A Stochastic Model to Set Sustainable Limits to Wildlife Mortality in a Changing World

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Extinction Vortex







Stochastic Events: **Random (chance) events** that can affect population dynamics Demographic stochasticity random fluctuation in obs. birth rate, death rate & sex ratio resulting from stochastic sampling processes



Stochastic Events: **Random (chance) events** that can affect population dynamics Demographic stochasticity **Environmental** stochasticity: fluctuation in probabilities of birth and death due to random fluctuations in

the environment

Stochastic Events can affect **Population growth** (*r*)

Long-term growth rates can be negative even with average positive *r*, if variation in growth rate is high

mean r = 0.125, SD = 0mean r = 0.125, SD = 0.55 Population Size 105000 50 1000Time Time **Stochastic** Deterministic (no stochasticity)

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But stochasticity is often ignored in simple population models (e.g. Leslie matrix), especially when determining sustainable limits to wildlife mortality

PILBARA FISH TRAWL FISHERY: BYCATCH OF BOTTLENOSE DOLPHINS

- Pilbara Fish Trawl Fishery (northern Western Australia) targets variety of scalefish species
- But also captures protected and threatened species, including bottlenose dolphins (*Tursiops truncatus*)





- Bycatch rates of bottlenose dolphins:
 - Skippers' logbooks (2012-2017):

24.5/yr (mean) (<u>73.5/3-yr</u>)

- Independent Observers (2002; 2006-2009): 50/yr (<u>150/3-yr</u>)
- Western Australian Department of Fisheries: 75/yr (225/3-yr) "number of dolphins caught by the fishery should be < 75/yr"

STOCHASTIC POPULATION MODEL USING VORTEX

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Set up **bycatch scenarios** based on estimated & reported bycatch rates, PBR:

- 73.5/3-yr
- 150/3-yr
- 225/3-yr
- **PBR: 48.57/3-yr** (16.19/yr)

- Used **Vortex** for population modeling
- Set up standard 3-yr model of a stable bottlenose dolphin population without bycatch:
 - Population size estimate from impacted Pilbara population
 - Vital rates from stable
 bottlenose dolphin population
 (Shark Bay, Australia; Manlik et al. 2016)





INTRODUCING SAMSE: SUSTAINABLE ANTHROPOGENIC MORTALITY IN STOCHASTIC ENVIRONMENTS



- Used **VORTEX** for population modeling to estimate **SAMSE limit**:
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• <u>Ran trial scenarios</u> that included the removal of a set number of individuals until we reached forecasts that produced non-negative stochastic growth rates, i.e. the **SAMSE limit**

SAMSE RESULTS



No	SAMSE	r _{det}	r stoch
1,619	2.33	0.0004	0.0001
2,953	4.33	0.0003	0.0001
5,473	8	0.0003	0.0001
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SAMSE ≈ 2-8 removals/year (7-24 per 3-yrs)

PBR vs SAMSE

PBR (Wade, 1998) $N_{MIN} (R_{MAX}/2) F_R$ $N_{MIN} = 1,619$ $R_{MAX} = 0.04$ (default for cetaceans) $F_{R} = 0.5$ (Wade, 1998) THUS PBR = $1,619 \times (0.04/2) \times 0.5 = 16.19$ **PBR*≈ 16** removals/year (48-49 per 3-yrs)

*Potential Biological Removal

(conventional method without stochasticity)

No	SAMSE	r _{det}	ľ stoch
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TO REACH OR MAINTAIN "OPTIMUM SUSTAINABLE POPULATION"

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No	SAMSE +1	l ldet	ľ stoch
<i>N₀</i> 1,619	SAMSE +1 2.67	<i>r_{det}</i> -0.0003	<i>r</i> stoch -0.0007
<i>N₀</i> 1,619 2,953	SAMSE +1 2.67 4.67	<i>r_{det}</i> -0.0003 -0.0001	<i>r</i> _{stoch} -0.0007 -0.0004

SAMSE ≈ 2-8 removals/year (7-24 per 3-yrs)

TO REACH OR MAINTAIN POPULATION STABILITY IN STOCHASTIC ENVIRONMENT



Parameters may include:

- Abundance estimates
- Carrying capacity
- Fishery bycatch rates

(a) Demographic Stochasticity:

Emerges from simulated occurrence of events based on specified probabilities

SAMSE:

 $r_{stoch} \ge 0$

Stochastic Model Trials to determine SAMSE: Increase mortality until threshold of +/- r_{stoch} is reached Stable Reference

Population

Parameters may include:

- Mortality rates
- Reproductive rates
- Age class distribution

(b) Environmental Stochasticity: Incorporate vital rate SD_{EV}: SD_{EV} = $\sqrt{\sigma^2_{Tot} - \sigma^2_{Samp}}$ Use binomial (or beta) distributions to sample annual

SAMSE + 1:

value from mean and SD_{EV}

 $r_{stoch} < 0$

Steps to follow: 1.) Setting up stochastic **model** based on parameters from impacted population and stable reference population 2.) Incorporating stochasticity: (a) Demographic stochasticity see diagram (a) (b) Env. stochasticity: see diagram (b) 3.) Trialing scenarios that reduce mortalities until reaching the threshold (= SAMSE) at which one additional mortality would forecast a negative stochastic population growth

Impacted Population Parameters may include:

- Abundance estimates
- Carrying capacity
- Fishery bycatch rates

(a) Demographic Stochasticity:

Emerges from simulated occurrence of events based on specified probabilities

SAMSE:

 $r_{stoch} \ge 0$

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Sta Parameters • Mortalit • Reprodu • Age class	Steps to follow: 1.) Setting up stored model based on from impacted p and stable refered population 2.) Incorporating	
o del mine ality d of	(b) Environmental Stochasticity: Incorporate vital rate SD_{EV} : $SD_{EV} = \sqrt{\sigma^2_{Tot} - \sigma^2_{Samp}}$ Use binomial (or beta) distributions to sample annual value from mean and SD_{EV}	 stochasticity: (a) Demographic see diagram (b) Env. stochastic see diagram 3.) Trialing scena reduce mortalitie
ined		(= SAMSE) at wh

SAMSE + 1: r_{stoch} < 0

stochastic on parameters d population erence ing hic stochasticity im (a) asticity: 1m (b) enarios that lities until hreshold which one additional mortality would forecast a negative stochastic population growth

Impacted **Population** Parameters may include:

- Abundance estimates
- Carrying capacity
- Fishery bycatch rates

(a) Demographic **Stochasticity:**

Emerges from simulated occurrence of events based on specified probabilities

SAMSE:

 $r_{stoch} \ge 0$

Stable Reference Population

Parameters may include:

- Mortality rates
- Reproductive rates
- Age class distribution

(b) Environmental **Stochasticity: Stochastic Model** Incorporate vital rate SD_{EV}: Trials to determine $SD_{FV} = \sqrt{\sigma^2}_{Tot} - \sigma^2_{Samp}$ Use binomial (or beta) Increase mortality distributions to sample annual until threshold of value from mean and SD_{FV} /- r_{stoch} is reached

SAMSE:

SAMSE + 1: $r_{stoch} < 0$

Steps to follow: 1.) Setting up stochastic **model** based on parameters from impacted population and stable reference population 2.) Incorporating stochasticity: (a) Demographic stochasticity see diagram (a) (b) Env. stochasticity: see diagram (b) **3.) Trialing scenarios** that reduce mortalities until reaching the threshold (= SAMSE) at which one additional mortality would forecast a negative stochastic population growth

WHAT IS SAMSE?

- Sustainable Anthropogenic Mortality in Stochastic Environments
- SAMSE is a population modelling approach that incorporates stochasticity to estimate sustainable limits to human-caused mortality of wildlife (not only bycatch!)
- **SAMSE-limit**: The maximum number of individuals that can be removed by human activity, without resulting in negative stochastic growth rate forecasts
 - Removing one more individual per year would result in a population decline, i.e. a negative stochastic r (= SAMSE +1)
- **SAMSE** allows us to incorporate stochasticity in the following ways:
 - Demographic stochasticity
 - Environmental stochasticity
 - <u>Dependency of offspring</u> on fate of parent(s) (e.g. dolphin calves that are dependent on mothers)

ADVANTAGES & LIMITATIONS OF SAMSE

- SAMSE can incorporate demographic stochasticity & environmental stochasticity
- **SAMSE** can incorporate surrogate data from well-studied, stable reference populations, i.e. does not require lots of data from impacted population
- **SAMSE** is broadly applicable to a large range of taxa and situations (not only bycatch)
- **SAMSE** can be performed using various off-the-shelf modeling software that allows the incorporation of stochastic factors, e.g. **VORTEX***, RAMAS

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- **SAMSE** often requires <u>surrogate data</u> from **reference population**:
 - <u>taxonomically & demographically similar</u> to human-affected population;
 - well-studied,
 - <u>stable</u> (in the absence of bycatch or other human-caused mortality)



ADVANTAGES & LIMITATIONS OF SAMSE

- SAMSE can incorporate demographic stochasticity & environmental stochasticity
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- SAMSE is broadly applicable to a large range of taxa and situations (not only bycatch)
- SAMSE can incorporate other threats (pollution, etc.); (akin to changing RMAX)
- **SAMSE** can be performed using various off-the-shelf modeling software that allows the incorporation of stochastic factors, e.g. **VORTEX***, RAMAS
- **SAMSE** often requires <u>surrogate data</u> from **reference population**:
 - <u>taxonomically & demographically similar</u> to human-affected population;
 - well-studied,
 - <u>stable</u> (in the absence of bycatch or other human-caused mortality)

*PLAN:

- Incorporate module into **VORTEX** to report **SAMSE-limit**
- Create "library" of preconfigured baseline
 VORTEX models for various species

THANKS FOR YOUR INTEREST!

Oliver Manlik (UAEU), Robert C Lacy, William B Sherwin, Hugh Finn, Neil R Loneragan, Simon J Allen

CONTRIBUTED PAPERS 🛛 🔂 Open Access 🛛 💿 🚯

Conservation Biology

A stochastic model for estimating sustainable limits to wildlife mortality in a changing world

Oliver Manlik 🔀, Robert C. Lacy, William B. Sherwin, Hugh Finn, Neil R. Loneragan, Simon J. Allen

First published: 04 February 2022 | https://doi.org/10.1111/cobi.13897

IUCN Conservation Planning Specialist Group, Species Conservation Toolkit Initiative SCTI: *SAMSE* to be incorporated into VORTEX



THANKS FOR YOUR INTEREST!

Oliver Manlik (UAEU) Opportunities for PhD at United Arab Emirates University:

- Population genomics fish (sardines, tuna)
- Gene expression in response to climate change (*Tigriopus*)

Contact me: oliver.manlik@uaeu.ac.ae Twitter: @Omanlik









WHAT IS **EFFECT OF STOCHASTICITY** ON FORECASTS?

	With Stochasticity	With Env Stochasticity	NO Stochasticity
Growth rate (r)	- 0.0233 to - 0.0972	– 0.0199 to – 0.0860	– 0.0196 to – 0.0832
% Change	- 17% to - 23%	- 2% to - 7%	NA

- Incorporating stochasticity substantially lowers population growth (by 17 to 23%), depending on population size
- Large effect of demographic stochasticity, in particular calf-mother dependency

- PBR estimates maximum number of animals that may be removed from a "stock" while allowing that stock to reach or maintain its "optimum sustainable population"
- **PBR** is considered to provide a <u>conservative limit</u> for human-caused mortality
- US Marine Mammal Protection Act (MMPA, 1972) provides statutory framework for PBR concept

PBR (Wade,1998): N_{MIN} ($R_{MAX}/2$) F_R N_{MIN} = Min N estimate R_{MAX} = 0.04 (default for cetaceans) F_R = 0.5 (Wade, 1998)

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- *PBR* is considered to provide a <u>conservative limit</u> for human-caused mortality
- US Marine Mammal Protection Act (MMPA, 1972) provides statutory framework for PBR concept
- Original equation/model is <u>deterministic</u>—i.e. does <u>not</u> <u>incorporate stochasticity</u>

PBR (Wade,1998): N_{MIN} ($R_{MAX}/2$) F_R N_{MIN} = Min N estimate R_{MAX} = 0.04 (default for cetaceans) F_R = 0.5 (Wade, 1998)

PBR (Wade, 1998):

 $N_{MIN} (R_{MAX}/2) F_R$

N_{MIN} = 1,619

```
R_{MAX} = 0.04 (default for cetaceans)
```

```
F<sub>R</sub> = 0.5 (Wade, 1998)
```

THUS PBR =

 $1,619 \ge (0.04/2) \ge 0.5 = 16.19$

PBR ≈ 16 removals/year (48-49 per 3-yrs)

TO REACH OR MAINTAIN "OPTIMUM SUSTAINABLE POPULATION"



Photo: Claire Daniel



PBR (Wade, 1998):

"The model used is deterministic rather than stochastic..."

"it would be useful to investigate the effects of stochastic dynamics through simulations which incorporated plausible levels of environmental variance"



Impacted Population

Parameters may include:

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 $r_{stoch} < 0$

Trials to determine SAMSE: Increase mortality until threshold of +/- r_{stoch} is reached

Stochastic Model

SAMSE: $r_{stoch} \ge 0$